



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<p>(21) International Application Number: PCT/NL92/00043 (22) International Filing Date: 5 March 1992 (05.03.92) (71) Applicant (for all designated States except US): TECHNISCHE UNIVERSITEIT DELFT [NL/NL]; Julianalaan 136, NL-2628 BL Delft (NL). (72) Inventors; and (75) Inventors/Applicants (for US only): WÓJTOWICZ, Marek, Andrzej [PL/NL]; Prof. Bosschardstraat 37, NL-2628 HL Delft (NL). MOULIJN, Jacob, Adriaan [NL/NL]; 2e Sweelinckstraat 144, NL-2517 HB 's-Gravenhage (NL). (74) Agent: SMULDERS, Th., A., H., J.; Vereenigde Octrooibureaux, Nieuwe Parklaan 97, NL-2587 BN The Hague (NL).</p>		<p>(81) Designated States: AT, AU, BB, BG, BR, CA, CH, CS, DE, DK, ES, FI, GB, HU, JP, KP, KR, LK, LU, MG, MN, MW, NL, NO, PL, RO, RU, SD, SE, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IT, LU, MC, NL, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, SN, TD, TG).</p> <p>Published With international search report.</p>
<p>(54) Title: METHOD AND APPARATUS FOR COMBUSTING A CARBONACEOUS MATERIAL</p>		
<p>(57) Abstract</p>		
<p>A method and an apparatus are described for combusting carbonaceous materials in a two-stage process. In a first reaction chamber (2), operating under fuel-rich conditions in a bubbling fluidisation regime, fuel undergoes primary combustion or gasification. Oxidising gas (5) is fed into the first reaction chamber at a velocity sufficient to maintain fluidisation. Combustion products leave the first chamber and enter a second reaction chamber (3), operating under oxygen-rich conditions as a circulating fluidised-bed combustor. A second stream of oxidising gas (6) is fed to the second chamber, preferably tangentially to generate a turbulent swirl. Particles of a sulphur-capture agent, preferably limestone, are fed to the second chamber, preferably with the second stream of gas. In the second stage, char and combustible gases generated in the first stage are burnt. The fuel-bound sulphur is removed and advantageously converted to calcium sulphate, while the fuel-bound nitrogen is advantageously converted to nitrogen gas.</p>		

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Title: Method and apparatus for combusting  
a carbonaceous material

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The present invention concerns a method for combusting a carbonaceous material in a two-stage process, comprising the steps of: in a first stage, combusting or gasifying said carbonaceous material under substoichiometric oxygen  
5 conditions; in a second stage, combusting at least part of the products formed in said first stage under excess stoichiometric oxygen conditions; and introducing a sulphur-capture agent into said process.

Such a method is known in practice. Combustion takes  
10 place at a temperature of about 700-1200 °C, the pressure being substantially atmospheric or elevated.

Carbonaceous materials, such as coal, may be burnt by contacting with oxygen-containing gas or they may be gasified by contact with an oxidising agent such as steam, carbon  
15 dioxide, air, or a mixture thereof, for instance in a fluidised-bed combustor (FBC). It should be understood that wherever reference is made in this text to "coal", this term is used for the sake of simplicity, and that the teachings of this invention extend to other carbonaceous materials, such as  
20 different types and grades of coal, oil shale, petroleum coke, peat, (municipal) solid waste, refuse-derived fuel, refinery and sewage plant sludges, liquid wastes and solid biomass material. Similarly, the term "air" is often used to denote any suitable oxidising gas.

25 In practice, a carbonaceous material contains nitrogen and sulphur, the combustion products of these elements providing environmental problems.

The nitrogen-containing products of combustion are mainly nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>), often referred  
30 to as NO<sub>x</sub>, nitrous oxide (N<sub>2</sub>O) and molecular nitrogen (N<sub>2</sub>). When combustion is performed under oxygen-rich, or oxidising,

conditions, the formation of NO<sub>x</sub> as nitrogen-containing species is favoured. When combustion is performed under fuel-rich, or reducing, conditions, the formation of N<sub>2</sub> or N<sub>2</sub>O as nitrogen-containing species is favoured. However, combustion  
5 under reducing conditions also results in incomplete combustion of carbonaceous material.

Except for N<sub>2</sub>, all the above-mentioned nitrogen-containing species are considered pollutants and thus are environmentally unacceptable.

10 Out of the three nitrogen-containing products of combustion (NO<sub>x</sub>, N<sub>2</sub>O and N<sub>2</sub>), it is NO<sub>x</sub> that has been given a lot of attention in recent years. However, N<sub>2</sub>O is known to be implicated in the greenhouse effect and in ozone layer  
15 depletion. Attempts to reduce NO<sub>x</sub> emissions resulted in the above-indicated technique which is often termed "staged combustion". In staged combustion, two zones are set up in series and the amount of air needed to combust a certain amount of carbonaceous material is divided into two streams. The first zone operates under fuel-rich conditions, with only  
20 a fraction of the total amount of air injected. In this way, emission of NO<sub>x</sub> from this stage is substantially lower than from a single-stage combustor, since in a reducing environment coal-bound nitrogen is converted primarily to N<sub>2</sub> and N<sub>2</sub>O. The remaining amount of air is introduced into the second zone  
25 (further downstream) where combustion of the fuel can be completed. This zone operates under oxidising conditions, yet producing only moderate amounts of NO<sub>x</sub> because nitrogen and nitrous oxide formed in the first zone do not undergo oxidation in the second stage. Therefore, the total emission  
30 of NO<sub>x</sub> is considerably lower than in a combustor without staging. Staged combustion may thus be viewed as a means to judiciously affect the selectivity of nitrogen conversion, i.e. formation of N<sub>2</sub> and N<sub>2</sub>O is favoured at the expense of NO<sub>x</sub>.

35 Until recently N<sub>2</sub>O was not recognised as an environmental pollutant. Its role in global warming phenomena was unknown and emissions of N<sub>2</sub>O were not monitored. Recent studies,

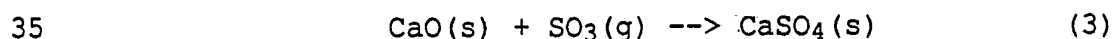
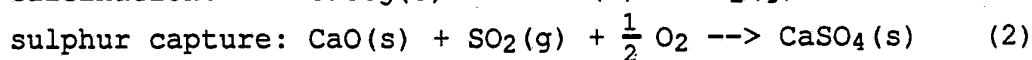
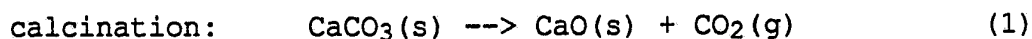
however, show unequivocally that substantial reduction in NOx emission from FBC, due to both relatively low combustion temperature (800 - 1000 °C) and staging, is accompanied by increased N<sub>2</sub>O levels. Combustion of fossil fuels is believed to be a major source of anthropogenic N<sub>2</sub>O and legislation limiting its emissions is expected to be passed in many countries within a few years.

Therefore, it is a first object of the present invention to provide a method for combusting a carbonaceous material in a two-stage process wherein the concentration of nitrogen oxides in combustion flue gases is reduced.

Sulphur-containing products of combustion or gasification are mainly sulphur dioxide (SO<sub>2</sub>), sulphur trioxide (SO<sub>3</sub>), hydrogen sulphide (H<sub>2</sub>S) and carbonyl sulphide (COS). These gases are all considered pollutants and thus are environmentally unacceptable. When combustion is performed under oxidising conditions, the formation of SO<sub>2</sub> as sulphur-containing species is favoured. Under reducing conditions, however, H<sub>2</sub>S and COS prevail in the products.

In the known method, a sulphur-capture agent is mixed with the fuel in the first stage in order to form a solid sulphur-containing product to be subsequently removed. Usually, as sulphur-capture agent CaCO<sub>3</sub> is mixed with the fuel, usually in the form of limestone or dolomite. In the following, the term "limestone" is used to denote any suitable sulphur-capture agent.

The following set of reactions provides a simplified overview of the underlying chemistry of sulphur capture:





In the above formulae, (s) is used to indicate a solid and (g) is used to indicate a gas.

5 It should be noted that unlike calcium sulphate ( $\text{CaSO}_4$ ), which is a neutral, environmentally acceptable solid by-product, calcium sulphide (CaS) is considered a pollutant due to its facility to decompose and form  $\text{H}_2\text{S}$  via reverse reaction (4).

10 Therefore, a drawback of this known method is that the removal and subsequent disposal of sorbent need to be done with care. Further, in this known method sulphur-capture is not efficient because of the reducing conditions that prevail in the first stage.

15 It is, therefore, a further object of the present invention to improve said known method to the extent that the capture of sulphur is improved. In particular, it is an object of the present invention to provide a more efficient sulphur-capture process wherein the sulphur-containing by-product is  
20 environmentally more acceptable, preferably safe, stable and disposable.

A further drawback of said known method is associated  
25 with the effect limestone has upon selectivity of fuel-bound nitrogen conversion to NO and  $\text{N}_2\text{O}$ . Upon entering a fluidised-bed combustor, a coal particle undergoes rapid devolatilisation. The volatiles, the amount of which can be substantial depending on the type of carbonaceous material  
30 used, comprise such nitrogen-containing species as  $\text{N}_2$ , ammonia ( $\text{NH}_3$ ) and hydrogen cyanide (HCN). Each of the latter two species is known to be an NO and  $\text{N}_2\text{O}$  gas-phase precursor, with  $\text{NH}_3$  producing mainly NO and HCN producing mainly  $\text{N}_2\text{O}$ . There is strong evidence that limestone addition to an FBC results in  
35 an over-all decrease in  $\text{N}_2\text{O}$  emission, accompanied by an increase in  $\text{NO}_x$  emission (see e.g. Moritomi, H., Suzuki, Y., Kido, N. and Ogisu, Y., "NO<sub>x</sub> emission and reduction from

circulating fluidized bed combustor," Proc. 3rd Int. Conf. on CFB, 15 - 18 Oct., 1990, Nagoya, Japan; or Gavin, D. G. and Dorrington, M., "Factors in the conversion of fuel nitrogen to nitric and nitrous oxides during fluidised bed combustion," Proceedings Int. Conf. on Coal Science, 16 - 20 Sep., 1991, Newcastle upon Tyne, U.K., pp. 347 - 350, Butterworth-Heinemann, 1991). It is believed that calcium oxide catalyses conversion of both  $\text{NH}_3$  and  $\text{HCN}$  to  $\text{NO}$ , thus counteracting to some extent the effect of staging.

10

It is, therefore, yet another object of the present invention to improve said known method to the extent that the capture of sulphur is performed in such a way that the formation of environmentally acceptable nitrogen-containing by-products is not disadvantageously affected.

15

In order to attain the above objectives, according to the invention said sulphur-capture agent is introduced in the second stage.

20

The first advantage of the method according to the invention is related to the capture of sulphur. In an oxidising environment, calcium sulphide decomposes to form  $\text{CaO}$  and  $\text{SO}_2$ , which subsequently react to yield calcium sulphate according to reaction (2). As mentioned before, calcium sulphate is a neutral, environmentally acceptable solid by-product. Moreover, sulphur retention by limestone is improved by its taking place under oxidising conditions.

25

A second advantage of the method according to the invention is related to the production of environmentally acceptable nitrogen-containing by-products. In an oxidising environment,  $\text{CaO}$  and  $\text{CaSO}_4$  have a strong catalytic activity towards decomposition of  $\text{N}_2\text{O}$  into  $\text{N}_2$  and  $\text{O}_2$ . Thus it should be appreciated that with respect to nitrogen-containing by-products, the effects of staging are improved: in the reducing atmosphere of the first stage, coal-bound nitrogen is, in the absence of limestone, converted primarily into  $\text{N}_2\text{O}$  and  $\text{N}_2$ ; in

30

35

the oxidising atmosphere of the second stage,  $N_2O$  is decomposed into  $N_2$  and  $O_2$  under the catalytic action of  $CaO$  and  $CaSO_4$ , thus resulting in a "clean" nitrogen product.

In summary, according to the present invention, a method and apparatus for combusting carbonaceous materials are proposed which have a high combustion efficiency, low emissions of  $NO_x$ ,  $N_2O$ ,  $SO_2$ ,  $SO_3$  and hydrocarbons, and which yield calcium sulphate as a safe, stable and disposable solid by-product.

10

The above-mentioned and other aspects, features and advantages of the present invention will become apparent and best understood by reference to the following description of the preferred embodiments, read in conjunction with the accompanying drawings, wherein:

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figure 1 schematically illustrates a first embodiment of a two-stage combustor according to this invention; and figure 2 schematically illustrates a second embodiment of a two-stage combustor according to this invention.

20

As shown in fig. 1, a two-stage fluidised-bed combustor 1 comprises a first-stage bubbling fluidised bed 2 and a second-stage circulating fluidised bed 3. The first stage 2 operates under fuel-rich, substoichiometric conditions and is fluidised by a stream of gas introduced to the system through the gas inlet 5. This gas will be subsequently referred to as primary air, although, in principle, any suitable gaseous oxidising agent can be used. Another stream of oxidising gas is introduced through a second gas inlet 6 into the second stage 3 of the combustor 1, and this stream will be referred to as secondary air. The second stage 3 operates under excess oxygen conditions to facilitate complete combustion. Oxygen supplied with the primary air usually constitutes about 40 - 70 % of the total amount used in the combustor 1, but this value may be different depending on a particular application.

30

The temperature of the first-stage combustion may be between 700 and 1200 °C, a value typical for an atmospheric fluidised-bed combustor (AFBC). Generally, the temperature in

the second stage is similar, or even somewhat higher, due to the high oxygen concentration in this part of the system and due to highly turbulent combustion. However, the process of the present invention is suitable for both atmospheric and high-pressure applications, depending on particular application, type of carbonaceous material used, etc.

Any carbonaceous materials that are appropriate for fluidised-bed combustion can be used in the process of this invention, such as different types and grades of coal, oil shale, petroleum coke, peat, (municipal) solid waste, refuse-derived fuel, refinery and sewage plant sludges, liquid wastes and solid biomass material. Coal is a preferred fuel and will be referred to in the detailed description of the preferred embodiment, without limiting the process of the present invention with respect to carbonaceous feed material. Coal is fed into the combustor 1 through a coal inlet port 4, and any suitable coal feeding device (not shown for the sake of simplicity) can be used to this end. Coal is usually crushed to a particle size below 5 mm and, in general, no other coal pretreatment is required.

Primary air and coal are brought into contact in the bubbling fluidised-bed 2 where the first stage of combustion takes place. The amount of oxygen introduced into the first stage 2 constitutes only a fraction of the total oxygen needed for complete combustion, preferably 40 - 70 %, as mentioned before. Under substoichiometric combustion conditions, most coal-bound nitrogen is converted to molecular nitrogen ( $N_2$ ) and nitrous oxide ( $N_2O$ ), the production of  $NO_x$  thus being minimised. Furthermore, the sulphur-containing combustion products at this stage are mainly  $SO_2$ ,  $H_2S$  and  $COS$ , in proportions depending on particular operating conditions.

Since no sulphur-removal steps are taken in the first stage 2, the whole inventory of all these species is subsequently transferred to the second stage 3. Small particles of coal are also entrained in the stream of gas leaving the first stage 2, and they undergo further combustion in the oxidising atmosphere of the second stage 3.

In the second combustion stage 3 particles of a sulphur-capture agent, preferably limestone or dolomite, are introduced, preferably having a particle size in the submillimeter range. These particles may be introduced  
5 separately, but preferably they are introduced together with the secondary air, as illustrated in fig.1. In this illustrated preferred embodiment, the limestone particles are stored in a bunker 7. The limestone particles are dispersed in the stream of secondary air 6 and the resulting mixture enters  
10 the second combustion stage 3.

The second combustion stage 3 may operate either as a typical circulating fluidised-bed combustor (CFBC), with limestone and secondary air introduced together or separately, or as a cyclonic CFBC, with limestone and secondary air  
15 introduced together through at least one, but preferably through a plurality of tangentially disposed inlet ports, as illustrated schematically in fig. 1, in quantities sufficient to generate a highly turbulent swirl.

High heat- and mass-transfer coefficients can be achieved  
20 in this zone, which facilitates heat recovery, efficient combustion, sulphur capture as well as solid-catalysed NO<sub>x</sub> and N<sub>2</sub>O reduction to N<sub>2</sub>. Sulphur removal takes place essentially only in the second stage, i.e. under oxidising conditions, which makes it possible to obviate difficulties associated  
25 with sulphur capture in a reducing environment. The limestone is ground preferably to submillimeter particle size to improve sulphur removal efficiency. The molar calcium-to-sulphur ratio typically used in FBC varies between 1 and 5. In combustors built according to the present invention, relatively low  
30 values of this ratio are possible (e.g. 1.5 - 2.5) due to small limestone particle size and high turbulence in the CFBC.

A mixture of flue gas, inert bed material (e.g. sand), fly ash and limestone exits the system through an outlet port situated in the top part of the combustor 1 and enters cyclone  
35 8, or any other suitable gas-solid separating unit. Upon completed separation, flue gas is directed to a stack, as indicated at 10, whereas solids are recycled to the bottom of

the second combustion stage 2, as indicated at 9. Fly ash and spent sorbent are removed from the system using any suitable method, which may be a known per se method, as indicated at 11. Similarly, a conventional method may be used to withdraw ash 12 from the bubbling fluidised bed.

The gas velocity in the second combustion stage 3 is preferably substantially higher than in the bottom part of the combustor 1, in order to prevent transfer of solids (such as sand or other inert material particles that constitute a circulating fluidised bed of the second zone, or the particles of a sulphur-capture agent introduced with the secondary air) from the second stage 3 to the first stage 2. This can be easily accomplished if, for example, the cross-sectional area of the second combustion zone is smaller than that of the first one. It is also possible that a relatively narrow passageway between said first reaction chamber 2 and said second reaction chamber 3 is provided. As illustrated in fig.1, a grid 14, preferably a perforated plate, may be provided between said first reaction chamber 2 and said second reaction chamber 3.

Good control over operating conditions of the process is possible through variation in coal feed rate and relative amounts of primary and secondary gas/oxygen supplied to the combustor 1. Thermal energy may be withdrawn from the process in either or in both stages using conventional methods such as internal or external heat exchangers, water jackets, etc. Heat removal is shown in fig. 1 only schematically at 13, without limiting the process of the present invention to this particular arrangement.

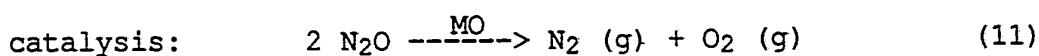
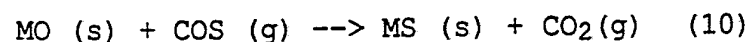
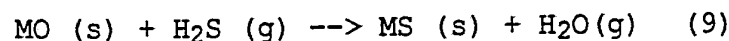
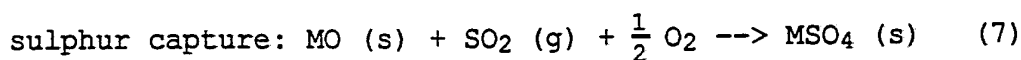
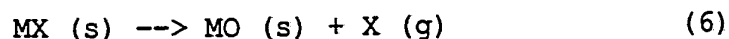
Furthermore, it will be apparent to those of ordinary skill in the art that various modifications and variations can be made to the above-described embodiment of the invention without departing from the scope of the invention. As an example, although the invention has been described in the context of staged combustion, it is apparent that the apparatus and method of the invention can be used for coal gasification by steam, carbon dioxide, air, mixture thereof,

or by any other suitable gasifying agent, realised in the first, i.e. bubbling, fluidised bed, followed by combustion of the generated gases and char in the second stage operating as a CFBC as described before. It should be borne in mind that gasification can be considered an extreme case of oxygen-starved combustion, and that any conventional gasifying agent, such as steam or carbon dioxide, can be employed.

Moreover, said fine particles of limestone or dolomite may be introduced via a separate entrance port. Another modification may involve the use of other catalysts or sorbents, in addition to or instead of a sulphur-capture agent. The role of such additives may be, for instance, enhancement of NO<sub>x</sub> and N<sub>2</sub>O reduction to molecular nitrogen.

As can be seen from the formulae (2)-(5), the active agent for sulphur-capture as described, is CaO. Of course it is possible to add CaO to the combustor, but it is equally well possible to add any precursor of CaO, such as Ca(OH)<sub>2</sub> or CaCO<sub>3</sub>, the latter being preferred because it is relative cheap and easily and abundantly obtainable.

However, other elements are suitable to be used in the process according to the invention, too, such as Mg, Ba, Sr, Fe, Al, Si, either alone or in combination, or in the form of an organic compound. In general, the following set of reactions illustrate the chemistry of sulphur-capture and catalysis:



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wherein M indicates any of the above-mentioned elements, and X indicates a group forming a suitable salt with M.

Another preferred embodiment 20 of the invention is presented in fig. 2. This combustor 20 differs from the above-described combustor 1 in the relative position of the first and second combustion stages 2 and 3. As shown in fig. 2, the stages 2, 3 are separated by a weir 21, over which material processed in stage 2 is transferred to the oxygen-rich stage 3. Although this configuration requires an additional ash disposal conduit 12a, as well as an additional fluidising gas inlet 5a, this configuration has an advantage over the embodiment shown in fig. 1 in the relative ease with which clearance between both stages 2 and 3 can be controlled by changing the height of weir 21. Moreover, the gas inlet 5a can be considered as a secondary air inlet, with the gas inlet 6 being considered as optional. Again, like in the embodiment shown in fig. 1, the element of swirl in the circulated fluidised bed is an optional feature of the system.

The essential idea of the invention is preserved in keeping circulation of limestone restricted to the oxidising zone of the combustor 1, 20. In fact, the point of injection of limestone 7 can be positioned at any convenient position in the second combustion stage 3, as obvious to those skilled in the art. Except for the differences discussed above, both preferred embodiments 1 and 20 according to the invention remain essentially identical. Corresponding parts of both systems are denoted by the identical reference numbers.

As a further modification, the degree of entrainment of coal particles into the upper, circulating fluidised-bed region can be controlled by varying the coal feed rate into the reactor and/or the inlet flow rate of the gas.

It is expressly stated that, although in the preferred embodiments described above the first combustion stage 2 is described as being a bubbling stage and the second combustion stage 3 is described as being a circulating stage, other combinations of combustion types are also possible, such as bubbling-bubbling, circulating-circulating, or circulating-bubbling. Moving beds are also conceivable.

## C L A I M S

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1. Method for combusting a carbonaceous material in a two-stage process, comprising the steps of:
    - a) in a first stage, combusting or gasifying said carbonaceous material under substoichiometric oxygen conditions;  
5
    - b) in a second stage, combusting at least part of the products formed in said first stage under excess stoichiometric oxygen conditions; and
    - c) introducing a sulphur-capture agent into said process;  
10characterised in that:
    - d) said sulphur-capture agent is introduced in the second stage.
  2. Method according to claim 1, characterised in that said  
15 sulphur-capture agent contains CaO.
  3. Method according to claim 1 or 2, characterised in that said sulphur-capture agent contains a precursor of CaO.
  - 20 4. Method according to any of claims 1-3, characterised in that said sulphur-capture agent contains a precursor of CaCO<sub>3</sub>.
  5. Method according to any of claims 1-4, characterised in that said sulphur-capture agent contains limestone or  
25 dolomite.
  6. Method according to any of claims 1-5, characterised in that said sulphur-capture agent is introduced in the form of fine particles, preferably having a particle size in the  
30 submillimeter range.

7. Method according to any of claims 1-6, characterised in that said sulphur-capture agent is introduced together with the secondary air.

5 8. Method according to claim 7, characterised in that said sulphur-capture agent is introduced in the form of fine particles dispersed in the secondary air.

9. Method according to claim 7 or 8, characterised in that  
10 the secondary air is introduced in quantities sufficient to generate a highly turbulent swirl.

10. Method according to any of the previous claims,  
characterised by adding a nitrogen oxide reduction catalyst to  
15 the second stage.

11. A process for fluidised-bed combustion of sulphur- and nitrogen-containing carbonaceous materials in a two-stage combustor comprising:  
20 introducing a sulphur- and nitrogen-containing carbonaceous material into a first stage which operates as a bubbling fluidised bed, fluidised by a gas introduced from the bottom through a suitable distributor;  
combusting or gasifying said carbonaceous material in said  
25 fluidised bed under substoichiometric oxygen conditions at temperatures about 700 - 1200 °C and under atmospheric or elevated pressure, producing char, ash and combustion gases, said combustion gases comprising gaseous sulphur and nitrogen species;  
30 converting said nitrogen contained in said carbonaceous material primarily into molecular nitrogen and nitrous oxide in the reducing region of said first stage;  
removing ash from said first stage through an ash withdrawal conduit;  
35 passing said combustion gases, char and fly ash into a second stage of the combustor which operates as a circulating fluidised-bed combustor (CFBC) with gas velocity substantially

higher than in said first stage;  
tangentially introducing a mixture of oxygen-containing gas,  
sulphur-capture agent and/or a catalyst enhancing reduction of  
nitrogen oxides to molecular nitrogen into said second stage  
5 to create a turbulent swirl;  
keeping circulation of said sulphur-capture agent and/or  
catalyst limited to the said second combustion stage;  
burning said char and those of said combustion gases formed in  
said first stage that are combustible in said second stage of  
10 said combustor at a temperature similar to that prevailing in  
said first stage and under excess stoichiometric oxygen  
conditions to produce second-stage combustion gases comprising  
sulphur and nitrogen oxides;  
reacting said particles of said sulphur-capture agent with  
15 sulphur oxides to form an environmentally acceptable solid by-  
product;  
reducing said nitrogen oxides to molecular nitrogen in said  
second stage;  
removing from said second stage flue gases, fly ash and  
20 particles of said sulphur-capture agent and/or said nitrogen  
oxides reduction catalyst and directing them to a cyclone or  
another gas-solid separating unit;  
separating said particles in said cyclone, or said gas-solid  
separating unit, from said flue gases, now comprising  
25 environmentally acceptable levels of CO, NO<sub>x</sub>, SO<sub>x</sub> and  
hydrocarbons, and recycling said particulates to the bottom of  
said second stage;  
removing said flue gases from said cyclone, or said gas-solid  
separating unit, and directing them to a stack; and  
30 removing from said second stage said fly ash and spent said  
sulphur-capture agent and/or said nitrogen oxides reduction  
catalyst through a fly ash/spent sorbent discharge conduit.

12. A two-stage fluidised-bed combustor for combusting a  
35 carbonaceous material, comprising:  
a first reaction chamber for holding a fluidised bed,  
preferably a bubbling fluidised bed;

means for feeding carbonaceous fuel into said first reaction chamber;

means for supplying a first stream of oxidising or gasifying agent to said fluidised bed at the bottom of said first

5 reaction chamber at a velocity sufficient to maintain fluidisation;

a second reaction chamber for holding a fluidised bed, preferably a circulating fluidised bed, the second reaction chamber having an entrance part communicating with an exit

10 part of the first reaction chamber;

means for supplying a second stream of oxidising gas to said second reaction chamber; and

means for introducing a sulphur-capture agent into the combustor;

15 characterised in that said sulphur-capture agent introducing means are adapted to introduce particles of said sulphur-capture agent into said second reaction chamber.

13. A two-stage fluidised-bed combustor according to claim 12,  
20 characterised in that said sulphur-capture agent introducing means comprise a bunker for storing said particles of said sulphur-capture agent, said bunker communicating with said means for supplying said second stream of oxidising gas.

25 14. A two-stage fluidised-bed combustor according to claim 13, characterised in that said means for supplying said second stream of oxidising gas comprise at least one tangentially disposed inlet port.

30 15. A two-stage fluidised-bed combustor according to any of claims 12-14, characterised in that separating means are provided for separating said second reaction chamber from said first reaction chamber in order to suppress a migration of sulphur-capture agent particles from said second reaction  
35 chamber to said first reaction chamber.

16. A two-stage fluidised-bed combustor according to any of claims 12-15, characterised in that said first and second reaction chambers are disposed side by side and are separated by a weir.

5

17. A two-stage fluidised-bed combustor according to any of claims 12-15, characterised in that said second reaction chamber is disposed on top of said first reaction chamber, and that said separating means comprise a narrow passageway  
10 between said first reaction chamber and said second reaction chamber.

18. A two-stage fluidised-bed combustor according to any of claims 12-15, characterised in that said second reaction  
15 chamber is disposed on top of said first reaction chamber, and that said separating means comprise a grid, preferably a perforated plate, between said first reaction chamber and said second reaction chamber.

20 19. A two-stage fluidised-bed combustor according to any of claims 16-18, characterised in that said means for supplying said second stream of oxidising gas are adapted to introduce second stream of oxidising gas at the bottom of said second reaction chamber.

25

20. A two-stage fluidised-bed combustor comprising:  
a first reaction chamber for holding a bubbling fluidised bed preferably having a relatively short freeboard to facilitate entrainment of fine particles of fuel;  
30 means for feeding carbonaceous fuel into said bubbling fluidised bed;  
means for supplying a first stream of gaseous oxidising agent to said bubbling fluidised bed through a plurality of openings at the bottom of said first reaction chamber at a velocity  
35 sufficient to maintain fluidisation;  
means for withdrawing ash from said bubbling fluidised bed;  
a cylindrical second reaction chamber for holding a

circulating fluidised bed connected with said first reaction chamber by a suitable conduit;

means for tangentially supplying a second stream of oxidising gas to said second reaction chamber through at least one

5 opening in said second reaction chamber at a velocity sufficient to create a turbulent swirl;

means for introducing particles of sulphur-capture agent and/or a nitrogen oxide reduction catalyst into said second stream of gas prior to its being fed into said second reaction  
10 chamber;

means for separating solid particles from flue gas and recycling said particles to the bottom of said second reaction chamber and said second reaction chamber being constructed in a manner adapted to: (i) prevent solid particles present in  
15 said second reaction chamber from entering said first reaction chamber, and (ii) provide sufficient turbulent gas-solid contact and residence time to successfully remove sulphur and nitrogen oxides from said flue gas as well as to allow for complete combustion of char and combustible gases;

20 means for withdrawing fly ash and spent said sulphur-capture agent and/or said nitrogen oxide reduction catalyst from the recycle loop of solid particles in said second reaction chamber;

25 means for recovering thermal energy from said two-stage fluidised-bed combustor.

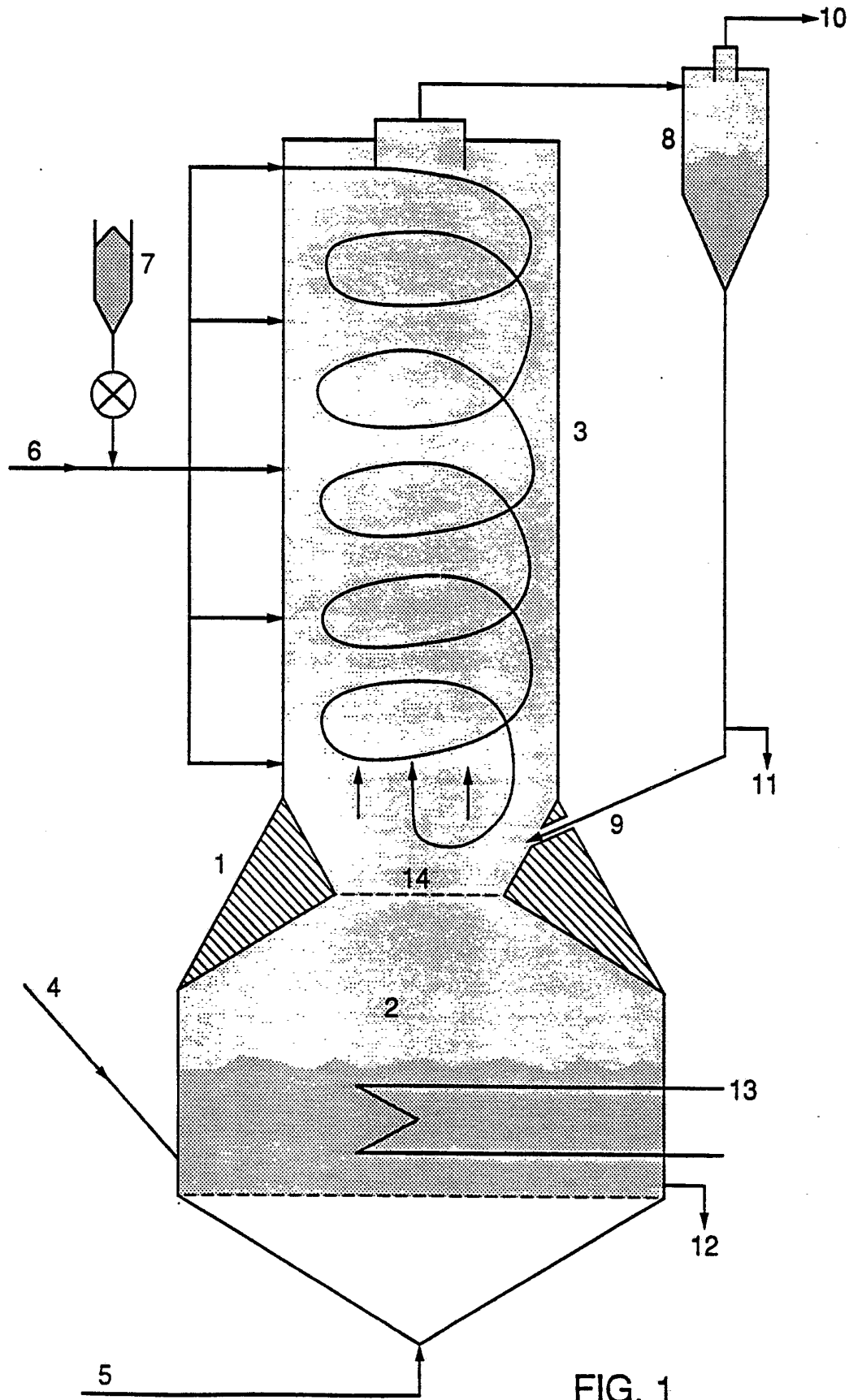


FIG. 1

SUBSTITUTE SHEET

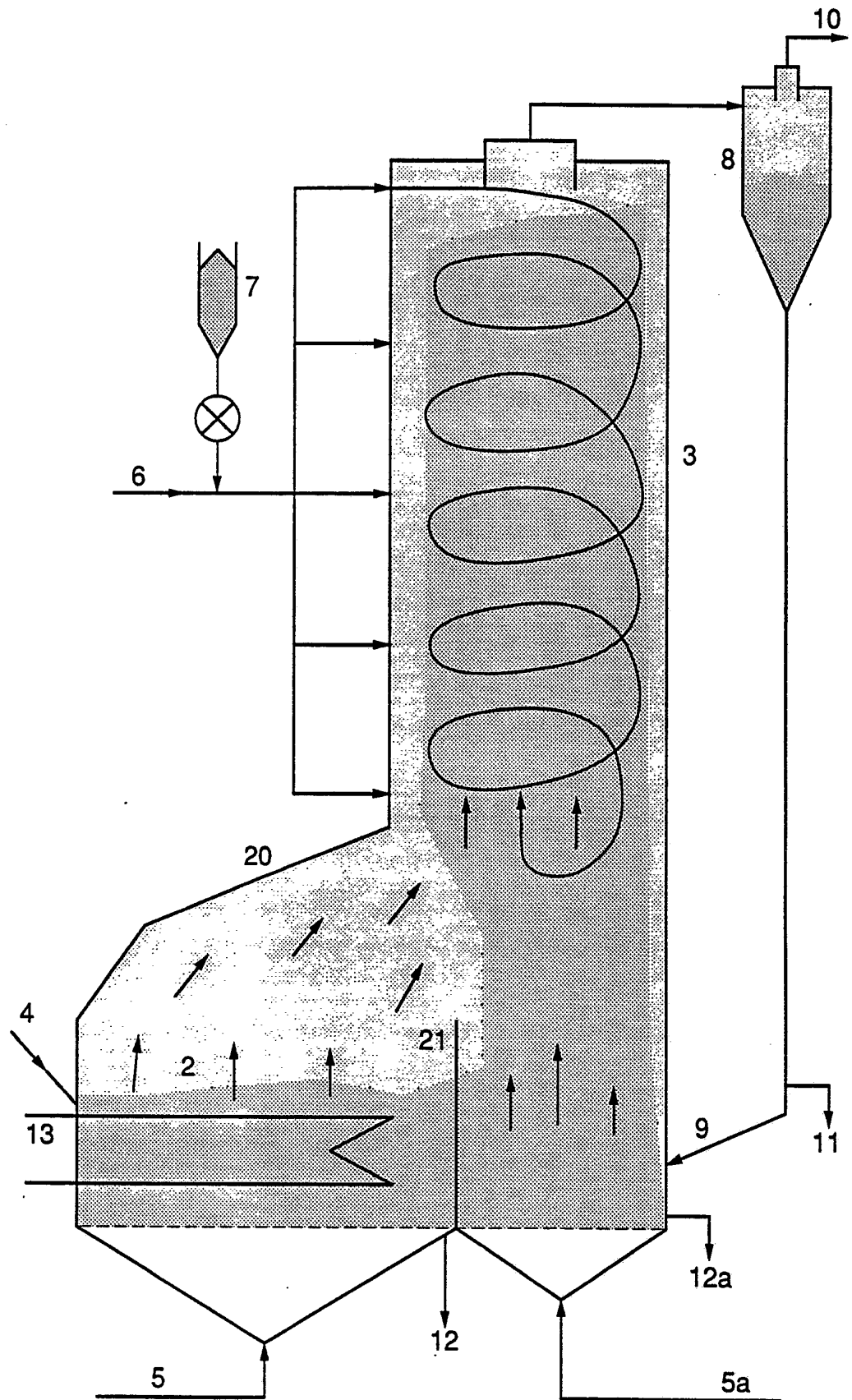


FIG. 2

## INTERNATIONAL SEARCH REPORT

PCT/NL 92/00043

International Application No

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC Int.Cl. 5 F23C11/02; F23C6/04; F23J7/00		
II. FIELDS SEARCHED		
Minimum Documentation Searched?		
Classification System	Classification Symbols	
Int.Cl. 5	F23C	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>		
III. DOCUMENTS CONSIDERED TO BE RELEVANT <sup>9</sup>		
Category <sup>o</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
X	EP,A,0 308 300 (FIVES-CAIL BABCOCK) 22 March 1989 see column 1, lines 3 - 12, 32 - 63 see column 2, line 33 - column 3, line 2 see column 3, line 65 - column 4, line 4 see figures 1,2	1,3,5,6, 12,15
Y	---	2,10,18 11,20
A	---	---
Y	WO,A,8 701 790 (OY TAMPELLA AB) 26 March 1987 see page 6, line 4 - page 7, line 13 see page 7, last paragraph - page 8, last paragraph see figure	2,10,18
A	---	11,20
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<sup>o</sup> Special categories of cited documents : <sup>10</sup> "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "&" document member of the same patent family		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
03 NOVEMBER 1992	29. 12. 92	
International Searching Authority	Signature of Authorized Officer	
EUROPEAN PATENT OFFICE	PHOA Y.E.	

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
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X	GB,A,2 159 432 (A. AHLSTROM CORPORATION) 4 December 1985 see the whole document	1,4,5, 12,15,17
X	PATENT ABSTRACTS OF JAPAN vol. 3, no. 29 (M-51)10 March 1979 & JP,A,54 1 437 ( KOGYO GIJUTSUIN(JAPAN) ) 8 January 1979 see abstract	1,12,18, 19
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A	EP,A,0 247 798 (DONLEE TECHNOLOGIES INC.) 2 December 1987 see column 18, line 31 - column 18, line 58; figure 1	16
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**ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO. NL 9200043  
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